Combination of Sodium Chlorite and Calcium Propionate Reduces Enzymatic Browning and Microbial Population of Fresh-Cut "Granny Smith" Apples

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ABSTRACT: Tissue browning and microbial growth are the main concerns associated with fresh-cut apples. In this study, effects of sodium chlorite (SC) and calcium propionate (CP), individually and combined, on quality and microbial population of apple slices were investigated. "Granny Smith" apple slices, dipped for 5 min in CP solutions at 0%, 0.5%, 1%, and 2% (w/v) either alone or in combination with 0.05% (w/v) SC, were stored at 3 and 10 °C for up to 14 d. Color, firmness, and microflora population were measured at 1, 7, and 14 d of storage. Results showed that CP alone had no significant effect on the browning of cut apples. Even though SC significantly inhibited tissue browning initially, the apple slices turned brown during storage at 10 °C. The combination of CP and SC was able to inhibit apple browning during storage. Samples treated with the combination of SC with CP did not show any detectable yeast and mold growth during the entire storage period at 3 °C. At 10 °C, yeast and mold count increased on apple slices during storage while CP reduced the increase. However, high concentrations of CP reduced the efficacy of SC in inactivating *E. coli* inoculated on apples. Overall, our results suggested that combination of SC with 0.5% and 1% CP could be used to inhibit tissue browning and maintain firmness while reducing microbial population.

Practical Application: Apple slices, which contain antioxidants and other nutrient components, have emerged as popular snacks in food service establishments, school lunch programs, and for family consumption. However, the further growth of the industry is limited by product quality deterioration caused by tissue browning, short shelf-life due to microbial growth, and possible contamination with human pathogens during processing. Therefore, this study was conducted to develop treatments to reduce microbial population and tissue browning of "Granny Smith" apple slices. Results showed that an antimicrobial compound, sodium chlorite, is effective in not only eliminating microbes but also inhibiting tissue browning of apple slices. However, the compound caused tissue softening and its antibrowning effect was short-lived, lasting only for a few days. Combination of the compound with a calcium-containing food additive was able to improve firmness and freshness of apple slices while reducing population of *Escherichia coli* artificially inoculated on samples and inhibiting the growth of yeast and mold during storage.

Keywords: browning, calcium propionate, *E. coli*, fresh-cut apples, sodium chlorite, yeast and mold

THE Society for Food Science & Technology
Journal of Food Science
A Publication of the Institute of Food Technologists

Introduction

Recently, there has been an increasing market demand for minimally processed (fresh-cut) fruits and vegetables due to their fresh-like character, convenience, and human health benefits. However, the fresh-cut industry is still limited by product quality deterioration caused by physiological disorders induced by cutting and microbial growth on the cut surface of produce (Lu and others 2007).

Fresh-cut apples which contain antioxidants and other nutrient components, have recently emerged as popular snacks in food service establishments, school lunch programs, and for family consumption (Gorny 2003). They generally have a short shelf life because of enzymatic browning, tissue softening, and microbial growth (Rupasinghe and others 2005, 2006; Lu and others 2007; Ruiz-Cruz and others 2007). In addition, the microbial safety of fresh-cut apples is a concern due to potential carryover of human pathogens (such as *E. coli* O157:H7) from whole apples and contamination of antibrowning solutions with *Listeria monocytogenes* during processing (Karaibrahimoglu and others 2004).

Browning is the main physiological disorder that impairs sensory properties and discourages consumer purchase of fresh-cut apples. Many chemical-preservative formulas composed mainly of ascorbic acid, a calcium source and an organic acid (such as Ca ascorbate) have been proposed as dipping treatments for fresh-cut apples to inhibit the browning and extend the postcut shelf life (Pizzocaro and others 1993; Son and others 2001; Fan and others 2005). However, most of those chemicals have limited success in extending the shelf life of fresh-cut apples because of low efficiency,

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doi: 10.1111/j.1750-3841.2009.01470.x

off flavors, and injury (Rupasinghe and others 2005; Lu and others 2007). In addition, these compounds have no or little antimicrobial activity against spoilage or foodborne pathogens (Rupasinghe and others 2005).

Sodium chlorite (acidified) in the concentration range of 0.05% to 0.12% has been approved by the Food and Drug Administration (FDA) for spray or dip application on various food products, including fresh and fresh-cut produce (Ruiz-Cruz and others 2006). Studies have shown that acidified sodium chlorite (ASC) has a strong antimicrobial efficacy against various human pathogens on fresh and fresh-cut fruits and vegetables (Park and Beuchat 1999; Martinez-Sanchez and others 2006; Ruiz-Cruz and others 2006; Kim and others 2007). Sodium chlorite (SC) probably has a dual role in browning inhibition and strong pathogen inactivation (He and others 2008). Lu and others (2007) reported that low concentrations of ASC and SC strongly inhibited enzymatic browning on fresh-cut apples. However, tissue injury and damage manifested as tissue softening was apparent on shredded carrots treated with ASC (0.1%, 2 min) (Ruiz-Cruz and others 2006), and more browning was apparent on fresh cut apples treated with acidified or nonacidified SC (0.1%, 1 min) (Lu and others 2007).

Application of calcium is effective in reducing softening in whole and fresh-cut fruit due to its stabilization of membrane systems and formation of calcium (Ca) pectates, which increases the rigidity of the middle lamella and cell walls (Aguayo and others 2008; Pinheiroa and Almeida 2008). Calcium propionate (CP) and propionic acid are used as antimicrobial food additives and are generally regarded as safe (GRAS) in the United States, with an upper limit only in some foods (Aguayo and others 2008). CP was effective in reducing microbial growth and maintaining fresh-cut "Amarillo" melon firmness and in decreasing the activity of pectin methylesterase in apples (Quiles and others 2007; Aguayo and others 2008). Furthermore, propionate is a more effective antilisterial agent than citrate or lactate (Kouassi and Shelef 1996) However, little information has been published concerning impact of various concentrations of CP, individually or in combination with a sanitizer, on browning and microbial quality of fresh-cut apples. Therefore, the present study was conducted to evaluate the efficacy of SC and CP, alone and in combination, on microbial growth, enzymatic browning and quality of fresh-cut "Granny Smith" apple at an ideal storage temperature and abusive temperature.

Materials and Methods

Plant material, processing, and packaging

Apple slice preparation. "Granny Smith" apples grown in Washington State were purchased from a distribution center in Philadelphia, and stored at 2 to 3 °C before use.

Processing of fresh-cut apples was performed in a 4 °C clean-processing room. All cutting boards, holding vessels, and then the fruit surfaces were sanitized with 200 ppm chlorine solution (pH 6.5) for 2 min and rinsed with deionized water before fresh-cut processing. An apple divider (Good Grips®, World Kitchen Inc., Reston, Va., U.S.A.) was used to slice the apples into 8 equal pieces and to remove the core. Each of the slices was immediately cut transversely into 2 pieces using a stainless steel blade (Chicago cutlery®, World Kitchen Inc.). The apple pieces were washed in solutions as described subsequently.

Treatment procedure. Fresh cut apples were submerged in the following 8 solutions: deionized water, CP solution (0.5%, 1%, 2%), SC (0.05%), and SC (0.05%) in combination with CP solution (0.5%, 1%, 2%). A concentration of 0.05% is the minimum concentration permitted by FDA for SC. Four pieces from each of 8 different apples was pooled together and treated in 1 of the dipping solutions for 4 to 5 min because the time required to slice 1 batch of apples was about 1 min. A total of 32 apple slices was treated in 500 mL solution. The slices were then drained using a stainless steel mesh strainer (NORPRO®, Everett, Wash., U.S.A.) and placed into plastic film bags (Ziploc®, Johnson & Son Inc., Wis., U.S.A.) perforated with 4 holes (0.8 cm in dia.). The bag sizes were approximately 16.5 × 14.9 cm, and there were 8 slices (approximately 80 g) per bag. The packaged apple slices were then stored at 3 and 10 °C until analysis. A temperature of 3 °C is an ideal temperature for fresh-cut apples while 10 °C is a temperature often found in local supermarkets. Color, texture, and microbial population were measured at 0, 1, and 2 wk (1, 7, and 14 d) of storage. Experiments were done in quadruplication.

Color measurement. Color (CIE L^*, a^*, b^*) was measured with a ColorQuest XE colorimetric spectrophotometer (Hunter Associates Lab., Reston, Va., U.S.A.) using a 1-cm measuring aperture. The spectrophotometer was calibrated using the standard light trap and a white tile (L^* 93.50, a^* −0.89, and b^* 1.01). D65/10° was the illuminant/viewing geometry. One reading on 2 cut surfaces was taken on each apple piece. Four apple slices for each replicate were measured, and there were a total of 16 measurements for each treatment per experiment.

Firmness measurement. Firmness was evaluated with a TA-XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, N.Y., U.S.A.). A 6-mm diameter probe was used to penetrate the centers of the transversely cut surface of apple slices to a depth of 10 mm at a speed of 10 mm/s. Three slices from each of 4 replicate bags were used for firmness measurements, and there were a total of 12. Maximum force was recorded using the Texture Expert software (version 1.22, Texture Technologies Corp).

Microbial enumeration. The microflora population was measured at 1, 7, and 14 d of storage. Each sample consisted of a stomacher bag (BagFilter, 400P, Spiral Biotech, Advanced Instruments Inc, Norwood, Mass., U.S.A.) containing 4 apple slices, typically 40 to 50 g of sample per bag. The precise weight of material was recorded for each sample, and 0.1% (w/v) sterile peptone water equal to sample weight was added, for example, 45 g apple + 45 mL 0.1% (w/v) peptone water. The sample bags were closed, the apple pieces broken up inside the bag, and then homogenized using a stomacher circulator (Model 400, Seward, London, England) for 2 min at 230 rpm.

A 1-mL aliquot of the apple wash solution was withdrawn and serially diluted in sterile 0.1% (w/v) peptone in 1 : 10 increments to a final dilution of 10^5. Separate 0.5 mL aliquots of each of the dilutions from 10^0 to 10^5 were withdrawn and pour plated on an appropriate medium, 2 plates per dilution. The total aerobic plate count (TAPC) was determined by plating the samples on tryptic soy agar (TSA, Difco™, Dickinson and Co., Sparks, Md., U.S.A.) and incubating at 37 °C for 24 h. Yeast and mold enumeration was performed by culturing with potato dextrose agar (PDA, Difco, Dickinson and Co.) and incubating at 27 °C for 4 to 5 d. The plate count values obtained, representing colony-forming units (CFU) per milliliter of wash buffer, were back calculated to account for dilution and weight of tissue to provide the final CFU per gram tissue values.

***E. coli* inactivation tests.** Inactivation tests were determined by following the procedure of Wang and others (2007). A nonpathogenic generic strain of *E. coli* (35218) was inoculated into six 50 mL sterile tubes each with 10 mL tryptic soy broth. The tubes were incubated overnight (24 h) in a 37 °C shaking incubator at 150 rpm. Bacterial cells were harvested by centrifugation (6000 rpm) at 4 °C for 10 min. The cell pellets were washed twice in peptone (0.1%

Bacto Peptone), and resuspended in 10 mL of 0.1% peptone water. The bacterial suspension was further diluted to 600 mL.

Processing of fresh-cut apples was performed as described above. Total of 32 slices of "Granny Smith" wedges were submerged in 600 mL of bacterial inoculum containing *E. coli* 35218 for 15 min with gentle agitation. The inoculated apple slices were drained and air-dried for 30 min in a laminar flow biological hood (Model MU-425-600, Nuare™, Plymouth, Minn., U.S.A.) before treatments. Inoculated apple samples, 4 slices (about 40 g) each, were then submerged in one of the previously mentioned 8 treatment solutions with an apple to solution ratio of 1 : 2.5 at 20 °C for 5 min with gentle agitation. Four slices (about 40 g) were removed from the solutions at the 5th min and immediately transferred to a sterile stomacher bag for microbiological analysis. The tests were repeated 3 times.

Statistical analysis. The experiment was designed as a randomized complete block with 4 replicates for each treatment except the *E. coli* inactivation study which was repeated 3 times. A bag with 8 slices of apples was regarded as a replicate, resulting in 32 slices each treatment/each sampling day. The least significant difference (LSD) test was used to test the effect of treatments during storage periods. All statistical analyses and calculations of means and standard deviations were performed by SAS 9.1 (SAS Inst. Inc., Cary, N.C., U.S.A.). Only significant difference ($P < 0.05$) was discussed unless otherwise stated.

Results and Discussion

Changes in color of fresh-cut apples during storage

Changes in L* value. L^*, depending on reflectivity of determined surface, was used to express lightness/darkness of sample surface (Du and others 2009). The higher the L^* value of fresh-cut apples was, the brighter the surface. The effect of SC, CP, and the combination treatments on L^* values of fresh-cut apples is shown in Figure 1. Generally, L^* tended to decrease with increasing storage, especially in samples treated with SC.

During storage at 10 °C, there was no significant difference in L^* values among water and CP treatments at day 1 and 7 (Figure 1A), while L^* values of samples treated by 1% and 2% CP were significantly higher than the control at day 14, indicating that the higher concentrations of CP reduced the development of darkness during storage. At 3 °C, there was no statistical ($P > 0.05$) difference in L^* values of the apple slices treated with 3 concentrations of CP from those treated with water (Figure 1B). Samples treated with 0.05% SC alone or in combination with different concentrations of CP had significantly higher L^* values than those corresponding treatments without SC at day 1 of storage at both temperatures (compare Figure 1C with 1A and 1D with 1B). However, L^* values of samples treated with SC alone began to decline dramatically during storage at 10 °C, and at the end of the storage (14 d), L^* values of the samples treated with 0.05% SC alone were significantly less than that of samples treated with combination of CP and SC. At 3 °C, there was no significant difference in L^* values among SC and SC + CP treatments during storage. It was also noted that SC + 2% CP caused core browning of the apple slices.

Our results suggest that SC caused tissue injury and the injured tissues darkened during storage, particularly at abusive temperature (10 °C). However, treating apple slices with combination of SC and CP reduced the darkening. Lu and others (2007) reported that SC inhibited browning of fresh-cut apples. However, L^* values between samples treated with SC and control tended to be similar at 14 d storage.

Changes in *a value.** Fresh-cut apples with increasing a^* values showed increasing redness (browning) of cut surface of apple slices and are indicative of enzymatic browning during storage. The higher the a^* values were, the redder (browning) the apples slices were. As shown in Figure 2, a^* values of all samples tended to increase with increasing storage time.

There was no statistical ($P > 0.05$) difference in a^* values of the apple slices treated with CP from those treated with water (Figure 2A and 2B). At day 1 of storage at either storage temperature, samples treated with SC or SC in combination with CP had significantly lower a^* values than those corresponding CP treatments, suggesting that the treatments with SC reduced tissue browning. a^* values of all samples treated with SC (alone or in combination with CP) increased during storage. However, the increase in a^* values in samples treated with SC was more rapid than that of samples treated with the combinations, particularly at 10 °C. The increases in a^* values during storage was reduced by the incorporation of CP and lower storage temperature.

Earlier studies have found that SC (0.02%) inhibited browning of apple slices (Lu and others 2007). However, the concentration was not allowed under current regulation as FDA called for the use of

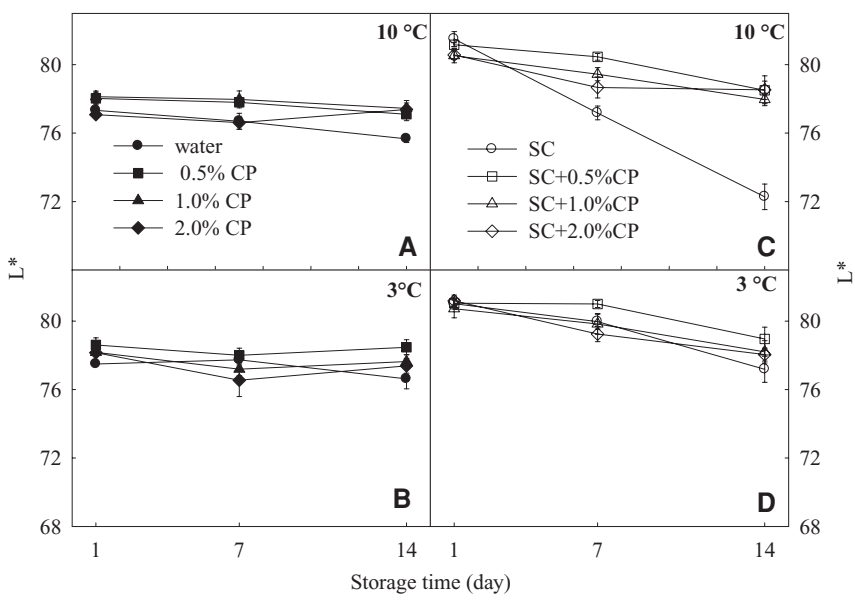

Figure 1 — Effect of SC and CP on *L values of fresh-cut apples. Vertical bars represent standard errors (*n* = 4).**

0.05% to 1.2% of SC to enhance microbial safety of fresh produce. In the present study, 0.05% SC could inhibit the browning of fresh-cut apple slices. However, the effect disappeared quickly during storage probably because of tissue injury. CP in concentrations of 0.5% to 2% significantly inhibited tissue browning caused by SC during storage at 10 °C. Although the combination of CP and SC was better in inhibiting browning of apple slices than the individual SC treatment, a browning in the core area of apple slices developed especially as the concentration of CP increased to 2% CP at the storage temperature of 3 °C. Compared to control treatment, CP alone could not inhibit browning of fresh-cut apples at 3 °C and only 2% CP had significantly inhibitory effect on browning at 10 °C.

Our results suggested that SC inhibited browning initially, but the inhibition was short-lived. The initial effect of SC to lighten the color of the apple surface may be a bleaching reaction. However, the subsequent effect of SC to increase browning during storage may be due to the oxidation of endogenous browning inhibitors, such as ascorbic acid or other antioxidants, or to the oxidation of enzymatic browning substrates or reaction products. The ability of CP to mitigate the probrowning effect of SC could be due to Ca-induced firming which might reduce leakage of browning substrates, or it might result from consumption of chlorite by reaction with propionate.

Changes in texture of fresh-cut apples during storage

The effect of CP, SC, and the combinations of the 2 on the firmness of fresh-cut apples is presented in Figure 3. SC had no significant effect on firmness of apple slices. However, firmness of apple slices generally increased with increasing CP concentration. Firmness of apples treated with various concentration of CP was frequently higher than that of samples treated with water and SC at 3 and 10 °C during the entire storage days. At the same time, there was no evidence of interaction between treatment and storage temperature.

It is well known that calcium chloride (Ca chloride) could maintain firmness of fresh-cut fruits such as kiwifruit, apples, strawberry, and mango slices. (Agar and others 1999; Fan and others 2005; Aguayo and others 2008). However, CP was reported to be more effective than Ca chloride in maintaining fresh-cut fruit firmness (Saftner and others 2003; Aguayo and others 2008). The dipping in CP solution significantly decreased metabolic activity and provided a whitish color to melon flesh (Aguayo and others 2008). CP could increase bound Ca concentrations in cut melon by an average of 50% (Saftner and others 2003). In addition, Ca consolidates structures and maintains the integrity of the parenchyma of fresh-cut apples because calcium reinforces cell walls. Furthermore, CP may also reduce the enzymatic activity of pectin methyl esterase (Quiles and others 2007) a firmness affecting enzyme. In this experiment, CP either alone or in combination with SC significantly increased firmness of fresh-cut "Granny Smith" apple slices, and their effect intensified with increasing CP concentration.

Microbiological analysis

Bacteria was virtually not detectable on apple slices during storage at 3 and 10 °C for 14 d (data not shown), probably because the apples were washed in chlorinated water and processed under strict sanitization conditions.

Changes in yeast and mold counts of fresh-cut apples during storage at 10 and 3 °C. The changes in yeasts and mold counts on fresh-cut apples during storage at 10 and 3 °C are shown in Table 1. There was no detectable yeast and mold in day 1 in either storage temperature. Furthermore, at 3 °C, no yeast and mold was detectable on any fresh-cut apples at day 7. At day 14 and 3 °C, samples treated with 0.05% SC in combination with 0.5%, 1% and 2% CP did not show any detectable yeast and mold during the entire storage period. Yeast and mold were detected in samples from the other 5 treatments. SC alone did not have any effect on yeast and mold counts. The yeast and mold counts of samples treated with CP were generally lower (although not always significantly) than those treated with water and SC.

The yeast and mold counts were significantly higher on apples stored at 10 °C than those stored at 3 °C for all sampling days particularly for samples treated with SC alone. At 10 °C, the yeast and mold counts of most samples tended to increase with increasing storage time. Similar to samples stored at 3 °C, yeast and mold count decreased with increasing CP concentration regardless of the presence of SC. SC did not have any significant effect on yeast and mold count at day 7. At day 14 and 10 °C, yeast and mold counts of SC treated samples were 1.8 log CFU/g higher than those treated with water, suggesting that 0.05% SC facilitated favorable

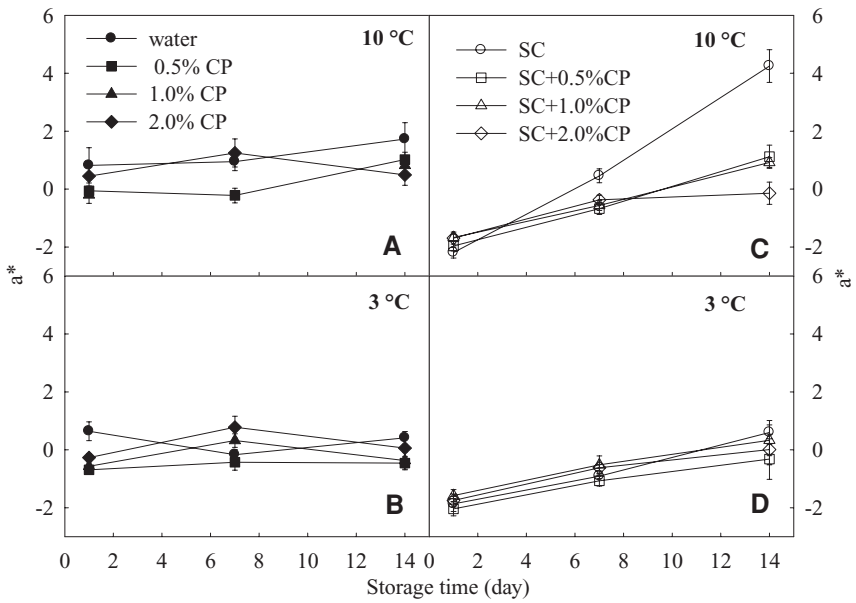

Figure 2—Effect of SC and CP on *a values of fresh-cut apples. Vertical bars represent standard errors (*n* = 4).**

conditions for yeast and mold growth during storage. In other studies, it was found that CP prolonged the shelf life of apples by delaying physiological disorders and microbial growth (Buta and others 1999; Aguayo and others 2008). In the present experiment, we demonstrated that CP could reduce the increase of yeast and mold counts caused by the injury of 0.05% SC.

The reducing effect of CP on microbial growth can be attributed to 2 aspects. One is that Ca can consolidate structures and maintain the integrity of plant cells to inhibit physiological breakdown (Buta and others 1999), and induce the synthesis of phytoalexins and/or phenolic substances (Aguayo and others 2008). The other is the antimicrobial properties of organic acid salts (Ca propionate). Their corresponding disassociated acids probably formed in solution and at the surface of fresh-cut fruits, which could uncouple microbial substrate transport and oxidative phosphorylation from the electron transport system, and lead to the reduced microbial counts (Aguayo and others 2008). The inhibitory effect of higher levels of CP on yeast and molds needs further research. To sum up our results, 0.05% SC promoted yeast and mold growth at 10 °C when compared to 0.5%, 1%, and 2% CP, while the combination with CP reduced the growth caused by 0.05% SC.

Effect of treatments on reduction of *E. coli* population. The population of *E. coli* inoculated onto fresh-cut apple surfaces after water dipping was 6.60 ± 0.12 log CFU/g tissue. There was no significant difference ($P > 0.05$) on *E. coli* reduction between the water and 0.5%, 1%, 2% CP dipping (Table 2). SC alone significantly ($P < 0.05$) reduced the population of *E. coli* by 3.95 log CFU/g inoculated on apple slices. However, the effect of SC on reduction of *E. coli* population decreased as the CP concentration increased. At 2% CP, SC only reduced 0.34 log CFU/g *E. coli*, which was not significantly different to water wash. This result showed that there was a chemical interaction between SC and CP. We speculated that the reaction is between SC and propionate because the combination of 0.05% SC with 0.5%, 1%, and 2% calcium chloride did not influence the effect of SC on reduction of *E. coli* population (data not shown). SC, when reacting with a weak acid, produces chlorous acid. Chlorous acid ($HClO_2$) is in equilibrium with chlorite ions: $HClO_2 = H^+ + ClO_2^-$. In addition, chlorine dioxide may be produced. All 3 SC-derived species (chlorous acid, chlorite ions, and chlorine dioxide) are strong oxidant agents. Because of the strong oxidant capacity, SC is capable of reducing population of bacteria in various fresh produce (Ruiz-Cruz and others 2006; Kim and others 2007). It is possible that propionate reacts with SC and derived species in dipping solutions, thus decreasing the efficacy of SC in inactivating *E. coli* inoculated on the apple slices. The exact mechanism about the chemical reaction between SC and propionate needs further research.

There have been many studies demonstrating that SC is effective in reducing the population of various bacteria inoculated on fresh produce (Park and Beuchat 1999; Martinez-Sanchez and others 2006; Ruiz-Cruz and others 2006; Kim and others 2007). Our results confirmed the effectiveness of SC in inactivating *E. coli* on apple slices. Our results further showed that SC inhibited tissue browning of apple slices; however, the inhibition was short-lived. During storage, particularly at higher temperature (10 °C), apple slices treated with SC turned brown. While CP alone did not have

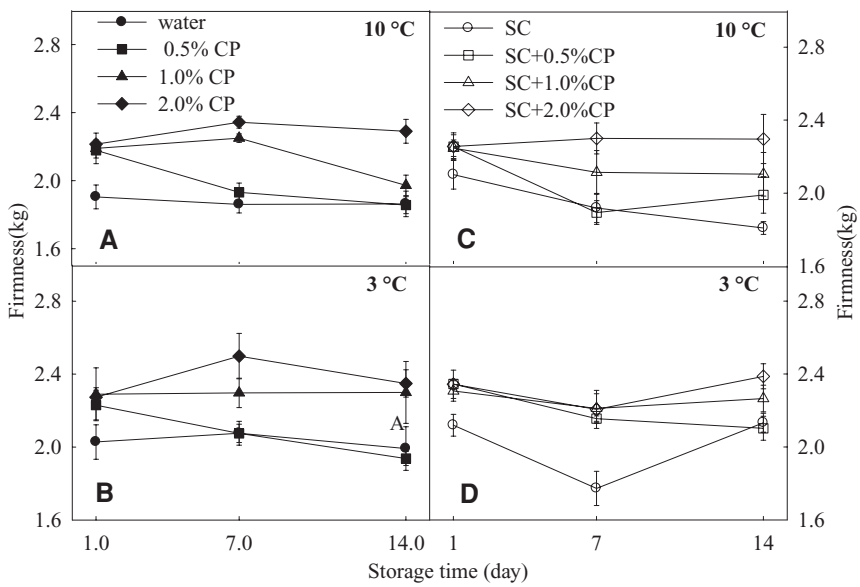

Figure 3 — Effect of SC and CP on firmness of fresh-cut apples. Vertical bars represent standard errors (*n* = 4).

Table 1 — Changes in yeast and mold counts (log CFU/g tissue) of fresh-cut apples during storage at 10 and 3 °C (*n* = 4).

	3 °C		10 °C	
Storage time (d)	7	14	7	14
Water	–	2.00 ± 1.55a	2.74 ± 0.59a	2.80 ± 0.47b
0.5% CP	–	1.02 ± 1.26ab	1.13 ± 1.31b	3.16 ± 1.20ab
1% CP	–	0.17 ± 0.35b	0.23 ± 0.15c	1.52 ± 1.76bc
2% CP	–	0.42 ± 0.51ab	0.08 ± 0.15c	0.79 ± 1.59c
0.05% SC	–	1.38 ± 1.60ab	2.85 ± 0.50a	4.60 ± 0.73a
0.05% SC + 0.5% CP	–	–	0.08 ± 0.15c	1.89 ± 1.73bc
0.05% SC + 1% CP	–	–	0.42 ± 0.52bc	1.21 ± 1.41bc
0.05% SC + 2% CP	–	–	–	–

Note: "–" below detection level (< 5CFU/g tissue). Data followed by different letters in the same column are significantly ($P < 0.05$) different among the treatments.

Table 2— *E. coli* population reduction on inoculated apple samples after 5-min treatment.

Treatment	Population reduction (log CFU/g tissue)	Treatment	Population reduction (log CFU/g tissue)[a]
Water	0 d[b]	0.05% SC	3.95 ± 0.20 a
0.5% CP	−0.06 ± 0.07 d	0.05% SC + 0.5% CP	2.11 ± 1.23 b
1% CP	0.06 ± 0.05 cd	0.05% SC + 1% CP	0.99 ± 0.79 c
2% CP	0.03 ± 0.05 d	0.05% SC + 2% CP	0.34 ± 0.48 cd

[a]Initial counts of *E. coli* on the apple piece (calculated according to water treatment) were 6.60 ± 0.12 log CFU/g tissue (means ± SD) ($n = 3$).
[b]Data followed by different letters in the same column are significantly ($P < 0.05$) different among the treatments.

a significant effect on the reduction of *E. coli* or tissue browning, when combined with SC, CP inhibited tissue browning of apple slices during storage. In addition to accelerating tissue browning during storage, SC also promoted the growth of yeast and mold during storage. Once again, when used with CP, the growth of yeast and mold was inhibited. Another benefit of CP was the improvement of firmness of apple slices.

Our results indicated that CP reduced the efficacy of SC in reducing *E. coli* population. At the highest concentration (2%) we tested, the bactericidal effect of SC was negated. However, at 0.5% or 1% CP, SC was able to significantly reduce the population of *E. coli* on apple slices Overall, our results suggested that 0.5% or 1% CP in combination with 0.05% SC could be used to reduce *E. coli* population and counter the growth of yeast and mold while maintaining firmness and inhibiting tissue browning of fresh-cut apples.

Currently, the fresh-cut industry uses antibrowning solutions to prevent discoloration. However, the antibrowning solutions can become contaminated with human pathogens, and washing of apple slices with the contaminated solutions can result in the transfer of pathogens to the product (FDA 2001; Karaibrahimoglu and others 2004). Even the combination of CP and SC used in the present study only achieved 1-2 log reduction of *E. coli* on apple slices, the treatment instantly eliminated *E. coli* in the solutions. Therefore, the treatment can be used to eliminate pathogens in solutions as well as to reduce possible pathogen present on apple slices.

Conclusions

While CP alone had little effect on tissue browning or population of *E. coli* inoculated on fresh-cut "Granny Smith" apples, CP maintained firmness of apple slices and reduced the growth of yeast and mold on fresh-cut apples. SC could reduce approximately 4 log CFU/g *E. coli* population inoculated on apple slices. SC initially inhibited tissue browning, but during storage, apple slices treated with SC developed browning much faster than other treatments, resulting in much more brown apples after 14 d of storage at 10 °C. Furthermore, SC treatment promoted yeast and mold growth during storage. When low concentrations (0.5 and 1%) of CP was combined with SC, the accelerated tissue browning and yeast and mold growth occurred during storage was inhibited while *E. coli* population could be reduced and firmness of apple was maintained. Our results clearly demonstrated the beneficial effects of the 2 compounds in improving microbial safety of fresh-cut apples while maintaining quality.

Acknowledgments

We thank Kimberly Sokorai, Lihan Huang, Aaron Williams, and Butch Scullen for technical assistance, Dr. John Philips for statistical analysis, and Drs. Gerald Sapers and Joshua Gurtler for critically reviewing the manuscript.

References

Agar IT, Massantini R, Hess-Pierce B, Kader AA. 1999. Postharvest CO_2 and ethylene production and quality maintenance of fresh-cut kiwifruit slices. J Food Sci 64:433–40.
Aguayo E, Escalona VH, Artes F. 2008. Effect of hot water treatment and various calcium salts on quality of fresh-cut 'Amarillo' melon. Postharvest Biol Technol 47:397–406.
Buta JG, Moline HE, Spaulding DW, Wang CY. 1999. Extending storage life of fresh-cut apples using natural products and their derivatives. J Agric Food Chem 47(1):1–6.
Du J, Fu Y, Wang N. 2009. Effects of aqueous chlorine dioxide treatment on browning of fresh-cut lotus root. LWT Food Sci Technol 42:654–9.
Fan X, Niemera BA, Mattheis JP, Zhuang H, Olson DW. 2005. Quality of fresh-cut apple slices as affected by low-dose ionizing radiation and calcium ascorbate treatment. J Food Sci 70(2):143–8.
[FDA] Food and Drug Administration. 2001. Enforcement report. Recalls and field corrections: foods–Class I. Recall number F-535-1. August 20, 2001. Sliced apples in poly bags. Available from: http://www.fda.gov/bbs/topics/ENFORCE/2001/ENF00708.html. Accessed Feb 16, 2009.
Gorny JR. 2003. New opportunities for fresh-cut apples. Fresh Cut 11:14–5.
He Q, Luo Y, Chen P. 2008. Elucidation of the mechanism of enzymatic browning inhibition by sodium chlorite. Food Chem 110:847–51.
Karaibrahimoglu Y, Fan X, Sapers GM, Sokorai K. 2004. Effect of pH on the survival of *Listeria innocua* in calcium ascorbate solutions and on quality of fresh-cut apples. J Food Prot 67(4):751–7.
Kim JG, Luo Y, Tao Y. 2007. Effect of the sequential treatment of 1-methylcyclopropene and acidified SC on microbial growth and quality of fresh-cut cilantro. Postharvest Biol Technol 46:144–9.
Kouassi Y, Shelef LA. 1996. Metabolic activities of *Listeria monocytogenes* in the presence of sodium propionate, acetate, lactate and citrate. J Appl Bacteriol 81:147–53.
Lu SH, Luo Y, Turner E, Feng H. 2007. Efficacy of sodium chlorite as an inhibitor of enzymatic browning in apple slices. Food Chem 104:824–9.
Martinez-Sanchez A, Allende, A, Bennett RN, Ferreres F, Gil MI. 2006. Microbial, nutritional and sensory quality of rocket leaves as affected by different sanitizers. Postharvest Biol Technol 42:86–97.
Park CM, Beuchat LR. 1999. Evaluation of sanitizers for killing *Escherichia coli* O157:H7, Salmonella and naturally occurring microorganisms on cantaloupes, honeydew melons, and asparagus. Dairy Food Environ Sanit 19:842–7.
Pinheiroa SCF, Almeida DPF. 2008. Modulation of tomato pericarp firmness through pH and calcium: implications for the texture of fresh-cut fruit. Postharvest Biol Technol 47(1):119–25.
Pizzocaro F, Torreggiani D, Gilardi G. 1993. Inhibition of apple polyphenolozidase (PPO) by ascorbic acid, citric acid and sodium chloride. J Food Process Pres 17:21–30.
Quiles A, Hernando I, Perez-Munuera I, Lluch MA. 2007. Effect of calcium propionate on the microstructure and pectin methylesterase activity in the parenchyma of fresh-cut Fuji apples. J Sci Food Agric 87:511–9.
Ruiz-Cruz S, Luo Y, Gonzalez RJ, Tao Y, Gonzalez GA. 2006. Acidified SC as an alternative to chlorine to control microbial growth on shredded carrots while maintaining quality. J Sci Food Agric 86(12):1887–93.
Ruiz-Cruz S, Acedo-Felix E, Diaz-Cinco M, Islas-Osuna MA, Gonzalez-Aguilar GA. 2007. Efficacy of sanitizers in reducing *Escherichia coli* O157:H7, *Salmonella* spp. and *Listeria monocytogenes* populations on fresh-cut carrots. Food Control 18:1383–90.
Rupasinghe HPV, Murr DP, DeEll JR, Odumeru J. 2005. Influence of 1-methylcyclopropene and natureseal on the quality of fresh-cut "empire" and "crispin" apples. J Food Qual 28:289–307.
Rupasinghe HPV, Boulter-Bitzer J, Ahn T, Odumeru J. 2006. Vanillin inhibits pathogenic and spoilage microorganisms in vitro and aerobic microbial growth in fresh-cut apples. Food Res Int 39(5):575–80.
Saftner RA, Bai J, Abott JA, Lee YS. 2003. Sanitary dips with calcium propionate, calcium chloride, or a calcium amino acid chelate maintain quality and shelf stability of fresh-cut honeydew chunks. Postharvest Biol Technol 29:257–69.
Son SM, Moon KD, Lee CY. 2001. Inhibitory effects of various antibrowning agents on apple slices. Food Chem 73:23–30.
Wang H, Feng H, Luo Y. 2007. Control of browning and microbial growth on fresh-cut apples by sequential treatment of sanitizers and calcium ascorbate. J Food Sci 72(1):1–7.